AUTONAV - Riedel

Abstract

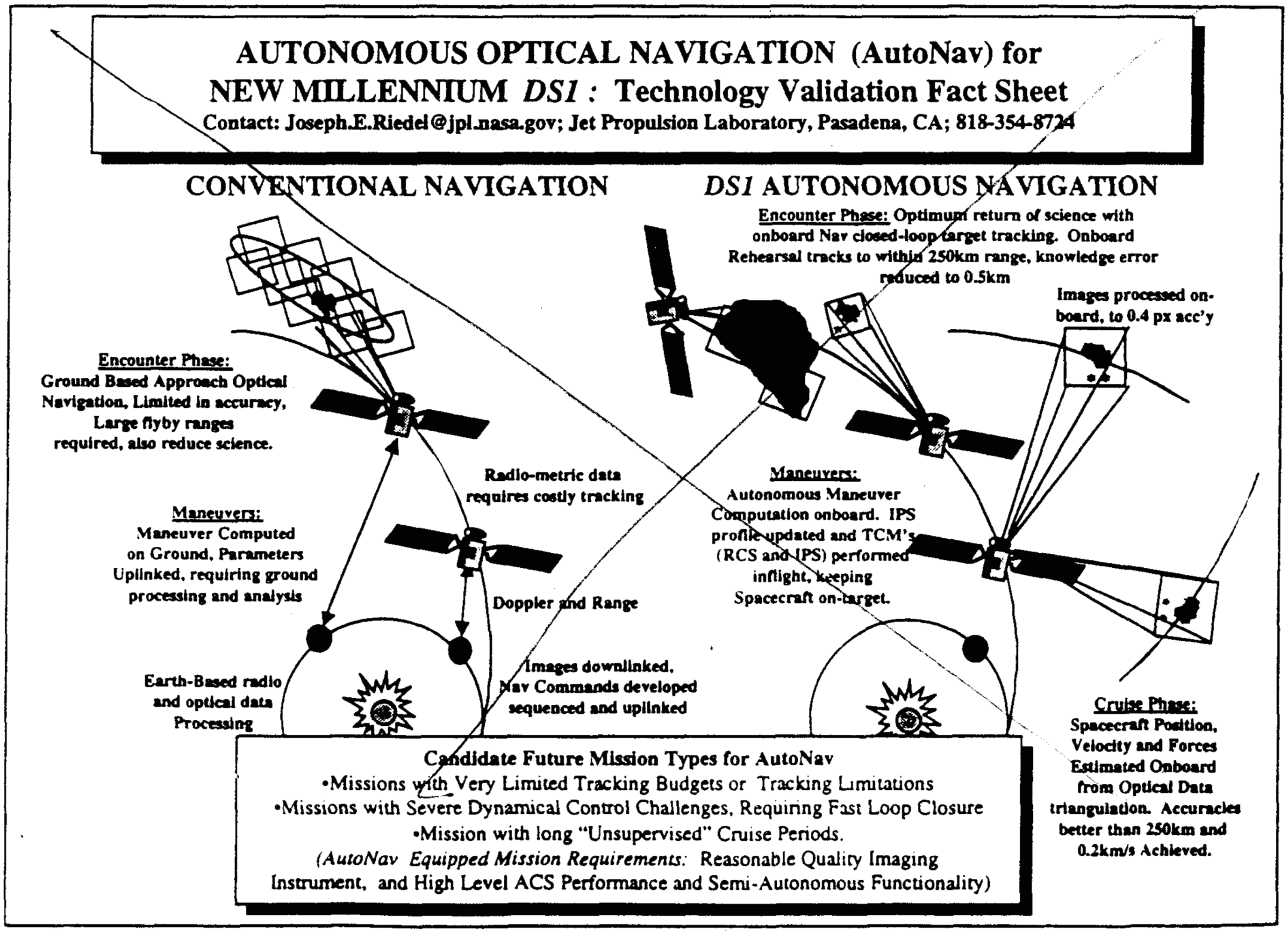
The first mission of NASA's New Millennium Program, *Deep Space 1*, has, as one of its principal demonstration-technologies, the first autonomous optical navigation system to be used in deep space. The concept of *DS1*, to develop and validate new technologies in the context of a low-cost deep space planetary mission, was an extremely challenging one. In practice the challenges were even greater. Nevertheless, the complete manifest of technologies was validated, with most of them proving highly successful, including the autonomous navigation system, AutoNav.

The theoretical basis of AutoNav is a process in which images of asteroids (typically main-belt) are taken against the distant stars, and through the measured parallax, geometric information is inferred. This information is used in a dynamic filter to determine the spacecraft position and velocity, as well as parameters describing the performance of the ion engine (IPS) and solar pressure. With this information, corrections to the mission design as described in the propulsion profile are made and/or predictions for necessary trajectory correction maneuvers (TCMs) are computed. This system is shown diagrammatically in the "Fact Sheet" Figure 1.

The AutoNav system is a set of software elements that interact with the imaging, attitude control and ion-propulsion systems aboard *DS1*. The principal elements and functions of AutoNav are: 1) NavRT, which provides critical ephemeris information to other onboard subsystems, such as the Attitude Control System, 2) NavExec, which plans and executes various important Nav related activities, such as image-taking and processing, Ion Propulsion System thrusting events, and TCMs, 3) ImageProcessor: the image processing subsystem, 4) OD: the orbit determination computation element, 5) ManeuverPlanner: which performs computations relative to the IPS events and the TCMs.

The Validation of the AutoNav system was to be accomplished through its use as the principal navigation system. As such, a comprehensive series of activities were planned to primarily accomplish the many navigation tasks for *DS1*, and secondarily to validate AutoNav. These tasks and their completion and/or validation status are shown in the "Fact Sheet" Table 1.

Figure 1: Fact Sheet Figure - Diagrammatic and Comparative Descriptionof AutoNav Technology and Validation



From the very first invocation of the higher functions of AutoNav, soon after launch in October of 1998, there were serious challenges. The imaging system onboard *DS1* suffered from serious light-leakage problems. As a result of this and a general lack of camera sensitivity, the availability of adequately bright asteroids to image was very limited. The light-leakage problems also seriously degraded the ability of the image-processor to reduce the data. Additionally, the geometric distortions of the camera field were much worse post-launch than pre-launch lab testing had indicated. All of these factors contributed to initial navigation errors of 10,000km and 7m/s in the spacecraft state. Nevertheless this was (and is) adequate quality for cruise operations of an interplanetary mission.

Efforts were immediately undertaken to compensate as much as possible for the camera short-comings. With a new load of software onboard in February of 1999, and a further update in June, performance gradually improved to the level of 250km and .2m/s, very nearly the pre-launch (and pre-anomaly) predicted performance, and substantially better than the validation requirement. On approach to the first of three encounter targets planned for the mission, AutoNav adjusted the IPS-powered course, and computed and executed TCMs. Three weeks before the Braille encounter, a "full dress" rehearsal of the encounter was performed, and AutoNav operated without problems, delivering the spacecraft to within the required 2.5km control parameter, tracking the target to within 30 seconds of closest approach, effectively reducing the field-of-view errors to within the required 0.5km.

During the actual close-approach of Braille, not surprisingly, unexpected conditions were encountered. The actual brightness of the asteroid was a factor of 5 to 10 below expectation and the camera channel used was 4 to 5 times less sensitive than designed and anticipated, resulting in previously set thresholds for discriminating real target signals not being crossed. As a consequence, the close-approach target tracking system of AutoNav did not "lock-on" to the target. Since the encounter sequence was aggressively "success oriented" and early (distant) images were not preserved onboard (due to a lack of storage RAM), the eagerly anticipated high-resolution images were not acquired. Nevertheless, important information was gathered about the operation of the *DS1* suite of technologies that will be applied to the encounters with comets Wilson Harrington and Borelly in 2001.

This report details the technology development, implementation strategy, testing methodologies and testing results as well as actual inflight success of the operation of the *DS1* AutoNav system.

Table 1 - "Fact Sheet" Table: AutoNav Technology Validation Key Point Summary

A	B: Technology Validation Item Description	C	D	E	F	G	H	I	J
1	Provision of Ephemeris Services	~10^5	~10^5	~10^5	0	≤0.1km	Req'd	<<0.1km	<<0.1km
2	Opnav PhotoOp Process	~40	47	46	1				
2a	Picture Planning	~40	47	47	0				
2b	ACS/APE Interaction & Turn Planning	~40	47	47	0				
2c	Mini-Sequence Picture/Turn/Fault Execution	~40	47	47	0				
3	Image Data Handling and Downlink	~40	47	47	0				
4	OpNav Data Accumulation, Handling, Downlink	~40	47	44	3				
5	Image Processing (RSS ensemble statistics)	~1200	~1500	~500	0	≤.25px	Desir'd	≤.40px	1.5px
6	Orbit Determination (Acc'y within data arc)	~32	34	34	0	≤250km, 1 m/s	Req'd	≤150km, 0.2 m/s	10000km, 7 m/s
7	Generation of Onboard Ephemeris, and Downlink	~32	34	34	0	.1-1km	Req'd	.1 km	1km
8	Trajectory Control and Maneuver Planning	~20	12	12	0				
8a	IPS Mission Burn Updates (Convergence criteria)	~12	6	6	0	≤1km	Desir'd	≤1km	≤1km
8b	IPS and RCS Maneuver Computations (do.)	~8	5	5	0	≤1km	Desir'd	≤1km	≤1km
8c	TCM Execution, and Delivery (Final TCM and accuracy – position and velocity)	8(2)	5(1)	5(1)	0	(≤2.5km, 0.25 m/s)	(Req'd)	(≤1.5km, 0.18 m/s)	(≤1.5km, 0.18 m/s)
9	Execution of Mission Burns	~12	7	7	0				
10	Encounter Image and OD Operations (RSEN)	2	2	1	0				
10a	Image Processing, and Data Reduction	~80	~80	~40	1				
10b	Ephemeris Generation and Delivery	~80	~80	~40	0	≤0.5km	Req'd	≤0.5km	15km
11	Encounter: Initiation of Encounter Sequences	8	8	8.	0	≤5sec	Desir'd	≤5sec	≤15sec

Legend- A: Item Number (Appendix G), B: Item Description, C: No. Planned In-Flight Executions, D: No. Actual In-Flight Executions, E: No. Successes In-Flight, F: No. Failures In-Flight (due to AutoNav Fault and/or Misuse), G: Quantitative Goal-Value (If Applicable), H: Required/Desired Quantitative Value, I: Best Value Achieved, J: Worst Value Achieved